Computer simulation of hydrogenated amorphous silicon solar cell.

Ayat Leila[1], Nour Sabra[1], MeftahAfak[2]

1 Laboratory of Semiconductor Devices Physic, *University of Bechar,PB 417,Bechar(08000),Algeria*
2 Laboratory of Semiconductors and Metals Materials, Université of Biskra, BP 145,Biskra(07000), Algeria

Abstract

This work is a numerical simulation of the output parameters of a PIN a-Si:H solar cell under AM1.5 spectrum. These parameters are the short circuit current (J_{sc}), the open circuit voltage (V_{oc}), the fill factor (FF), the conversion efficiency (η) and the spectral response (SR). The simulation was performed with SCAPS-1D software version 3.2 developed at ELIS in Belgium by Marc Burgelman et al. The obtained results are in agreement with experiment. In addition, the effect of the thickness and the defect density of the intrinsic layer (I) on the output parameters of the cell are also presented. It was found that a I layer thickness of 0.3 µm consists the optimum value for the cell efficiency as well for the spectral response. For the I layer defect density it was found that it induces a serious deterioration in the output parameters of the cell when the defect density exceeds 10^{16}cm-3.

Keywords: Amorphous silicon p-i-n junctions; Thin film; Solar cells; SCAPS-1D.

1. Introduction

Solar cells are expected to become most important energy source in the future when the fossil fuel is exhausted because an abundant amount of solar energy is constantly supplied on the surface of earth. Solar cells are already being utilized especially in the areas far from electric power plants. In order to further promote the spread of solar cells, lowering of the production cost is indispensable. Conventional Amorphous-silicon alloys have great promise as low cost solar cell materials. They have excellent photoconductivity and high optical absorption to sunlight.

* Ayat Leila. Tel.: +213778574378
E-mail address: ayat_leila@yahoo.fr

The most attractive features are their technological merits. They can be grown in large areas on any substrate material and have low balance of system cost. Their mass production lines can easily be automatized. However, long time exposure of sunlight over the solar cells of such materials degrades their efficiency. It is due to the sharp rise in the neutral dangling bonds on account of photostructural change in the basic material. This phenomenon is known as Staebler-Wronski effect [1]. The success of amorphous silicon alloys to solar cells and opto-electronics lies in developing high quality material which may be devoid of such photoinduced degradation.

In particular the properties of the intrinsec layer in a solar cell (thickness, doping), play a crucial role in its performances. In order to optimize them we analyzed their influence on the photovoltaic parameters of the cell. For that, we discuss the influence of thickness and density of defects in the intrinsic layer on external parameters of PIN a-Si:H solar cell. In this context, we use the software called SCAPS-1D (Solar Cell Capacitance Simulator in one dimension). SCAPS is a windows application program, made available to university researchers in the photovoltaic community after the second PV World Conference in Wien, 1998[2]. It solves structures with up to seven different layers, plus two contacts [3-5]
The obtained results agreed well with the reported experimental findings [6].

2. Theoretical model

The basic solar cell parameters are the short circuit current density J_{sc}, the open circuit voltage V_{oc}, the fill factor and the efficiency η [7-9].

The flow of carriers into the external circuit constitutes a reverse electrical current density which under short circuit conditions (V = 0) is known as the short circuit current density J_{sc} .

The separation of charges sets up a forward potential difference between the two contacts of the solar cell, which under open circuit conditions (I = 0) is known as the open circuit voltage V_{oc}.

The overall current voltage response of the solar cell, its current voltage characteristic, is the sum of the short circuit current and the dark current. The J-V characteristic is then described by :

$$J = J_0 \left[\exp \left(\frac{qV}{nkT} \right) - 1 \right] - J_{sc} \qquad (1)$$

Where J_{sc} is the saturation current density, q the elementary charge, k Boltzmann’s constant and T the absolute temperature.

n is called the diode quality factor, or the diode ideality factor. In the ideal Shockley theory, n = 1 or n = 2. In typical devices, the value of n ranges from 1 to 2[7-9].

J = 0 yields

$$V_{oc} = \frac{nkT}{q} \ln \left(\frac{J_{sc}}{J_0} + 1 \right) \qquad (2)$$

In real cells, the J-V curve deviates from the ideal Eq. (1) by parasitic effects, which can be described by tow resistances, one in series (R_s) and one in parallel (R_{sh}) with the cell. Serie resistance is due to the resistance of the cell material to current flow, especially through the front surface to the contacts. The parallel resistance can be due to a leakage current trough the cell [7-9].

Thus when parasitic resistances are included the diode equation (1) becomes :

$$J = J_0 \left[\exp\left(\frac{q\,(V - J\,R_s\,A)}{nkT} \right) \right] + \frac{(V - J\,R_s\,A)}{R_{sh} A} - J_{sc} \qquad (3)$$

The fill factor is a measure of the “squareness” of the J-V curve under illumination and is defined as the ratio :

$$FF = \frac{J_m V_m}{J_{sc} V_{oc}} \qquad (4)$$

Where J_m and V_m are respectively the values of current density and voltage at the maximum power condition.

The efficiency of the cell is the power density delivered at the maximum power point as a fraction of the incident light power density P_{inc} [7-9].

$$\eta = \frac{J_m V_m}{P_{inc}} \qquad (5)$$

3 Solar cell structure details

Figure 1 shows the structure of the cell used in the simulation. The structure is composed of a glass window, a transparent conductor oxide (TCO) anode, a P-I-N junction and a Al cathode. The input set used in our simulation is reported in Table 1.

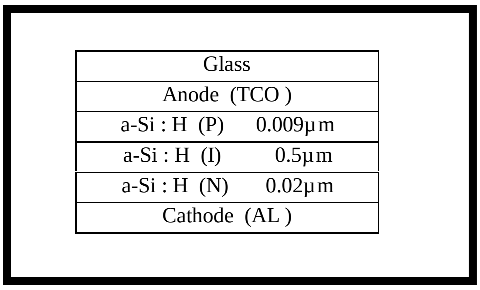

Fig. 1. a-Si:H p-i-n solar cell structure .

Parameter	p-layer	i-layer	n-layer
Layer thickness (nm)	9	500	20
Relative permittivity	7.2	11.9	11.9
Electron affinity (eV)	3.90	4.00	3.99
Mobility gap (eV)	1.95	1.78	1.80
Electron mobility (10^{-4} m^2/Vs)	20	20	20
Hole mobility (10^{-4} m^2/Vs)	5	5	5
Effective DOS in CB (m^{-3})	$1x10^{26}$	$1x10^{26}$	$1x10^{26}$
Effective DOS in VB (m^{-3})	$1x10^{26}$	$1x10^{26}$	$1x10^{26}$
Mid gap defect density (m^{-3})			

Table.1 Parameters used to simulate the a-Si:H solar cell

4 Results

4.1 Comparison between simulation and experimental

The standard measurements used to evaluate the performance of solar cells are J-V measurements in the dark and under different illumination conditions.

The solar cells are commonly characterized and compared by external parameters such as V_{oc}, J_{sc}, *FF*, and the conversion efficiency η, which are determined from *J-V* measurements under standard AM1.5 illumination. Additional measurements are the spectral response measurements that can be carried out under different bias voltage and bias illumination.

A comparison between the experimental [6] and the simulated *J-V* characteristic of the solar cell is presented in Figure 2 under AM1.5 spectrum and the extracted parameters in the tow cases are summarized in table 2. It can be concluded that there is an acceptable agreement between experimental values and the simulated one. A small difference is noticed only between the measured and the simulated V_{oc} values.

Parameters	Experimental [6]	Simulation
V_{co} (volt)	0.82	0.965
J_{ph} (mA/cm^2)	18.3	17.36
FF (%)	0.683	0.691
η (%)	10.3	11.59

Table. 2 : Experimental and simulated values of p-i-n hydrogenated amorphous silicon solar cell performance at T=300K under AM1.5 spectrum.

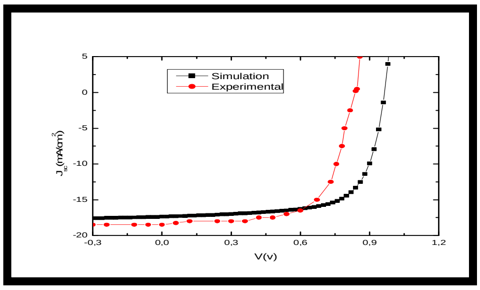

Figure.2 Experimental [6] and simulated J-V characteristic of the a-Si:H solar cell.

4.2. **The intrinsic layer thickness effect**

In this section we examine the effect of the i-layer thickness on J_{sc}, V_{oc} , FF and η. The obtained results are summarized in Figure 3. It was found that V_{oc} and FF show a decrease while J_{sc} increases when the i-layer thickness increases from 0.05µm to 0.4µm. The conversion efficiency η of the cell presents an optimum value for the i-layer thickness of 0.3µm.

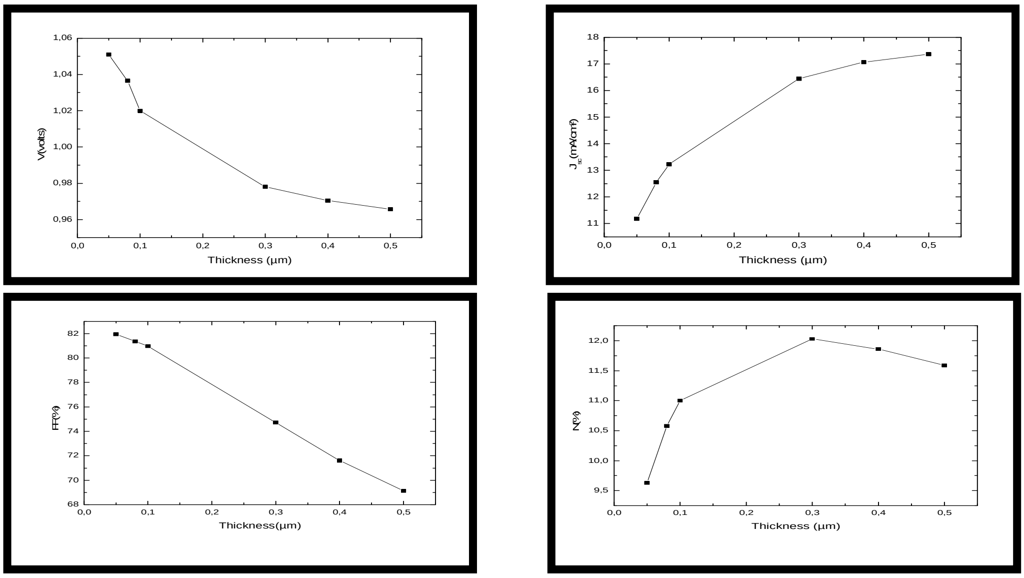

Fig. 3. Simulated photovoltaic parameters of the a-Si:H solar cell as a function of the i- layer thickness, (a) Open circuit voltage, (b) short circuit current density, (c) Fill factor, (d) Efficiency.

The decrease of V_{oc} with the increase of the i-layer thickness can be explained by the relationship between the electric field, and hence the voltage, with the i-layer thickness [10]. However for J_{sc} the i-layer is the active region of the absorption and the photogeneration. Then, increasing the i-layer means that more photons are absorbed and more free carriers are generated which lead to an enhancement in the photocurrent [10,11].

FF is the percentage of the collected pairs compared to created one. Since the a-Si: H has many defect states, many pairs are trapped and fewer are collected. Therefore when the i-layer thickness increases, the generation-recombination balance causes a general decrease of FF. On the other hand, the series resistance increases with the thickness of the i-layer which reduces the fill factor [10,11].

Finally and as result of the contribution of all previous parameters, the conversion efficiency η of the cell presents an optimum value of 12% for the i-layer thickness of 0.3μm . The a-Si:H intrinsic layers contains a smaller density of states in the gap than the doped layers, allowing the transport of carriers charge over distances of several hundred nanometers against a few nanometers doped layers. However, we needed to create a space charge region in the structure, but their thickness is reduced to a minimum in order to not deteriorate the collection of carriers.

4.2 Spectral response

The spectral response is similar to the quantum efficiency. The quantum efficiency gives the number of the generated electrons by the solar cell compared to the number of the incident photons, while the spectral response is the ratio of the current generated by the solar cell to the incident power on the solar cell. The spectral response is one of the characterization methods used to determine the device quality and proprieties under a given spectrum during the solar cells production.[7.][12]

The effect of i-layer thickness on the spectral response is shown in figure (4.7). The spectral response exhibits the same behavior as the cell efficiency. It increases with the i-layer thickness increase until a thickness of 0.3 µm after that it decreases. Then the 0.3µm is the optimum value of the i-layer thickness to have the best spectral response of the cell.

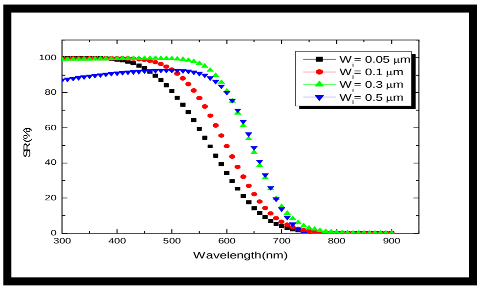

Figure.4 The effect of the thickness of the intrinsic layer on the spectral response.

4.3 Effect of i-layer defect density on the photovoltaic parameters

The dangling bond defect density is an important parameters which affects the transport properties of the a-Si:H solar cell. Therefore the defect density of the intrinsic layer was varied to quantify its effect on the output parameters of the cell.

Figure.4 display the plot of the V_{oc}, J_{sc}, FF and η under AM1.5illumination of a-Si:H p-i-n solar cells i-layer defect density.

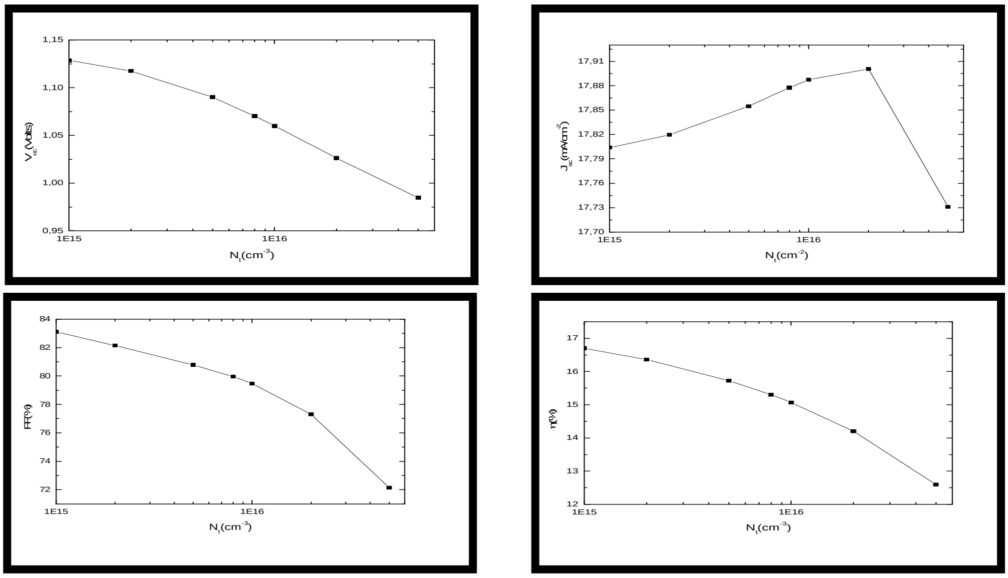

Fig. 4. Photovoltaic parameters of a-Si:H solar cell as a function of i-layer defect density, (a) Open circuit voltage, (b) short circuit current density, (c) Fill factor, (d) Efficiency.

The increase of the i-layer defect density causes a decrease in the V_{oc}. J_{sc} increases together with i-layer defect density, it reaches a maximum at about 10^{16} and then decreases, showing that losses due to bulk recombination. FF decreases significantly and its rate of decrease is enhanced by the enhancement of the i-layer defect density. We note that the fill factor is the most sensitive parameter to i-layer density of defects. The efficiency is significantly reduced by an increasing i-layer defect density. The general reduction of the efficiency is due to the deterioration of FF and Voc .

We conclude that a-Si: H photovoltaic parameters decrease when density of states increases. When the layers p, i and n are contacted; the free carriers due to diffusion of donors and acceptors to the intrinsic region under the effect of the concentration gradient. Following this distribution, there appears a fixed negative space charge in the p-layer and positive in n-layer. It then establishes an internal electric field that achieves equilibrium or flow of carriers (electrons and holes) vanishes.

In the case of the a-Si: H cells; this electric field allows separation of the photo-generated carriers in the intrinsic region and their collection. Ideally, the internal field is uniform. In fact, the intrinsic a-Si: H exhibits defaults; including dangling bonds, which influence the charge collection since firstly, they behave as recombination centers and secondly, they can induce a deformation internal field which is then no longer uniform.

Conclusion

We presented a simulation study of hydrogenated amorphous silicon P-I-N solar cells. The J-V characteristic is simulated under AM1.5 spectrum by SCAPS 3.2 and compared with experiments. An acceptable agreement is obtained.

The effect of the i-layer thickness on J_{sc}, V_{oc}, FF and the cell efficiency η is presented. J_{sc} increases while V_{oc}, FF decreases with a layer thickness ranging from 0.05 to 0.4µm. The cell efficiency η exhibit the best value of 12% for a i-layer thickness of 0.3µm. The same behavior is observed for the spectral response of the cell.

The effect of the defect density in the intrinsic layer is also presented. When the density exceeds $10^{16}cm^{-3}$ all cell parameters undergo a serious degradation.

References

[1] D. L. Staebler and C. R. Wronski, Appl. Phys. Lett. 31, 292 (1977); J. Appl. Phys. 51,3262 (1980).

[2] A. Niemergeers, S. Gillis, M. Burgelman, in *Proceedings of the Second World Conference on Photovoltaic Energy Conversion* (Wien, Osterreich, 1998),p.1071.

[3] M. Burgelman, P. Nollet, S. Degrave, Thin Solid Films 361, 527 (2000)

[4] M. Burgelman, P. Nollet, S. Degrave, Electronic behaviour of thin-film CdTe solar cells, Applied Physics A, 69 (1999),p. 149-153

[5] K. Decock, M. Burgelman, SCAPS Version 2.9.02, June 2010.

[6] R.E.I. Schropp, M. Zeman, Amorphous and Microcrystalline Silicon Solar Cells: Modeling, Materials, and Device Technology, Kluwer Academic Publishers, Boston, MA, USA, 1998.

[7] M. Orgeret, ‘Les Piles Solaires’, Edition Masson, pp. 185 , 1985.

[8] S. M. SZE, Physics of Semiconductor Devices, John Wiley & Sons, 1981..

[9] *A . Ricaud* , Photopiles solaires , première édition , Lausane , Suisse , (1997)

[10] Bouguenna Ibrahim Farouk, Modélisation et Optimisation d’une Cellule Solaire Tandem a-Si:H/a-SiGe, Magister thesis, 2009

[11] A. Fantoni, M. Vieira, R. Martins, Simulation of hydrogenated amorphous and microcrystalline silicon optoelectronic devices,1999.

[12] N. Benaouda, R. Aiouaz et M. Abersi, ‘Réponses spectrales et des caractéristiques I - V des cellules solaires au silicium’, Revue des Energies Renouvelables ICRESD-07, Tlemcen 2007, pp145 – 150.